# Evaluating the Assumptions in an Empirical Jet-Surface Interaction Noise Model

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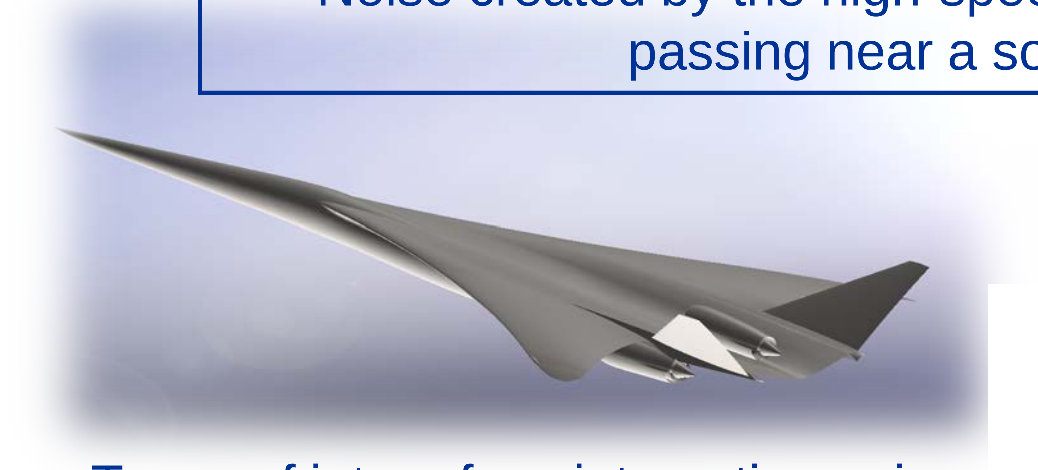
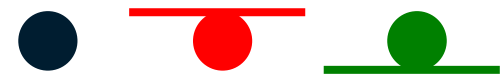
# Outline

- Jet-Surface Interaction (JSI) noise and effects
- Simple-Single-Stream Empirical Models
- Advanced geometry
- Required assumptions for complex flow and geometry
- EPNL predictions
- Spectral predictions – assess assumptions
- Conclusions

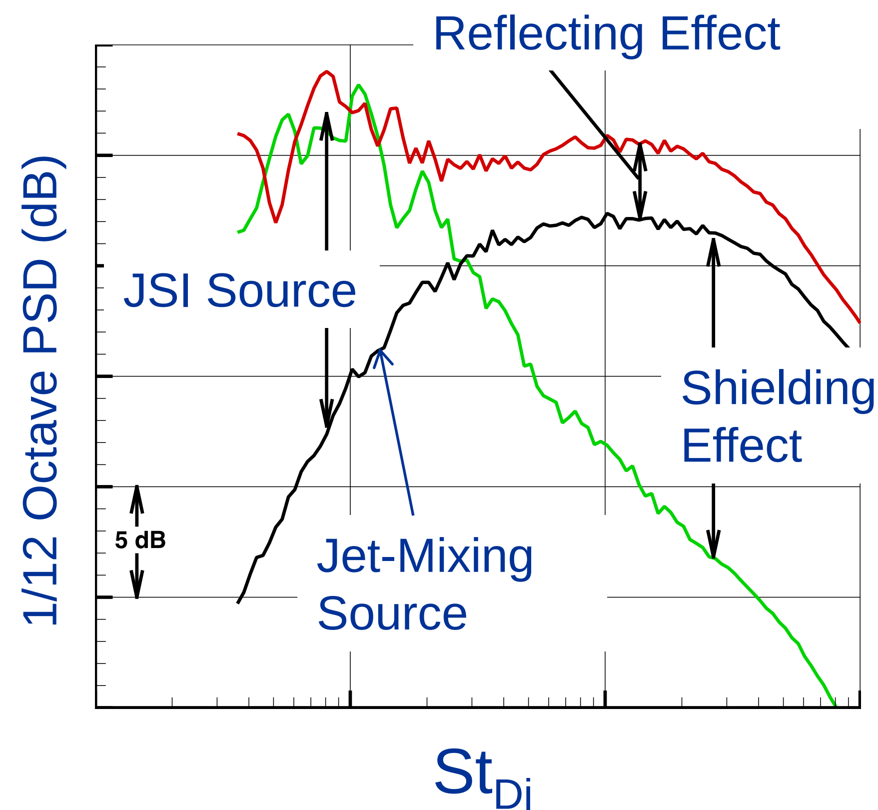
# Jet-Surface Interaction (JSI) Noise

Noise created by the high-speed jet exhaust striking or passing near a solid surface





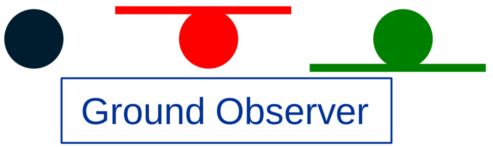

- Types of jet-surface interaction noise
  - Surface loading ("scrubbing") noise
  - Trailing edge ("scattering") noise
  - Surface vibration noise
- Measured far-field noise includes:
  - Jet-surface interaction noise sources
  - Jet mixing noise (isolated)
  - Shielding/Reflecting effect



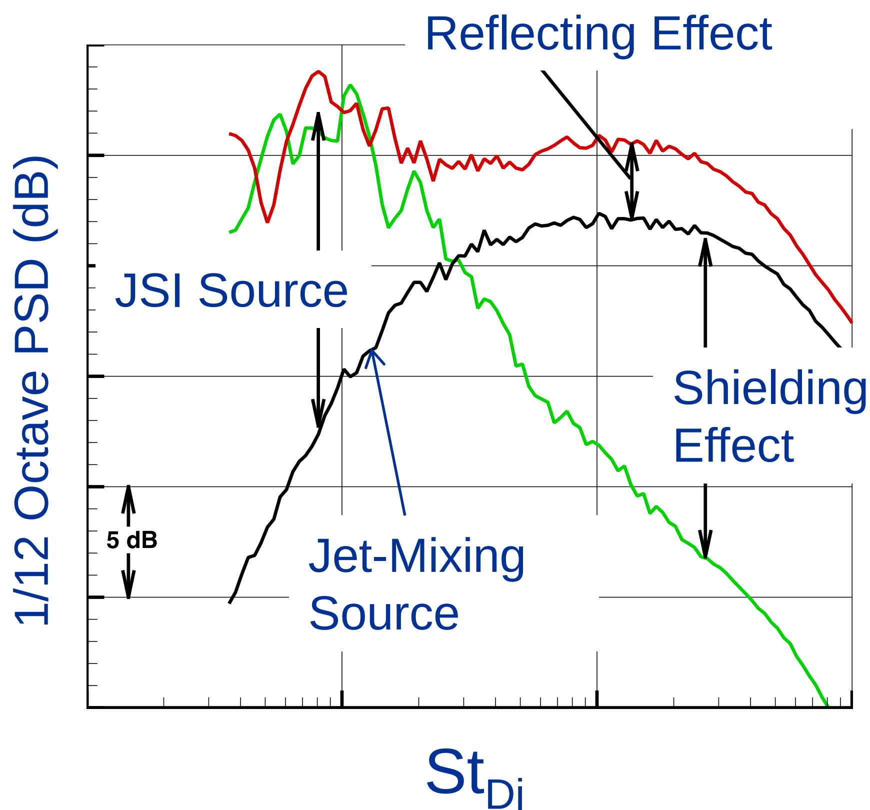
# Jet-Surface Interaction (JSI) Noise

Noise created by the high-speed jet exhaust striking or passing near a solid surface

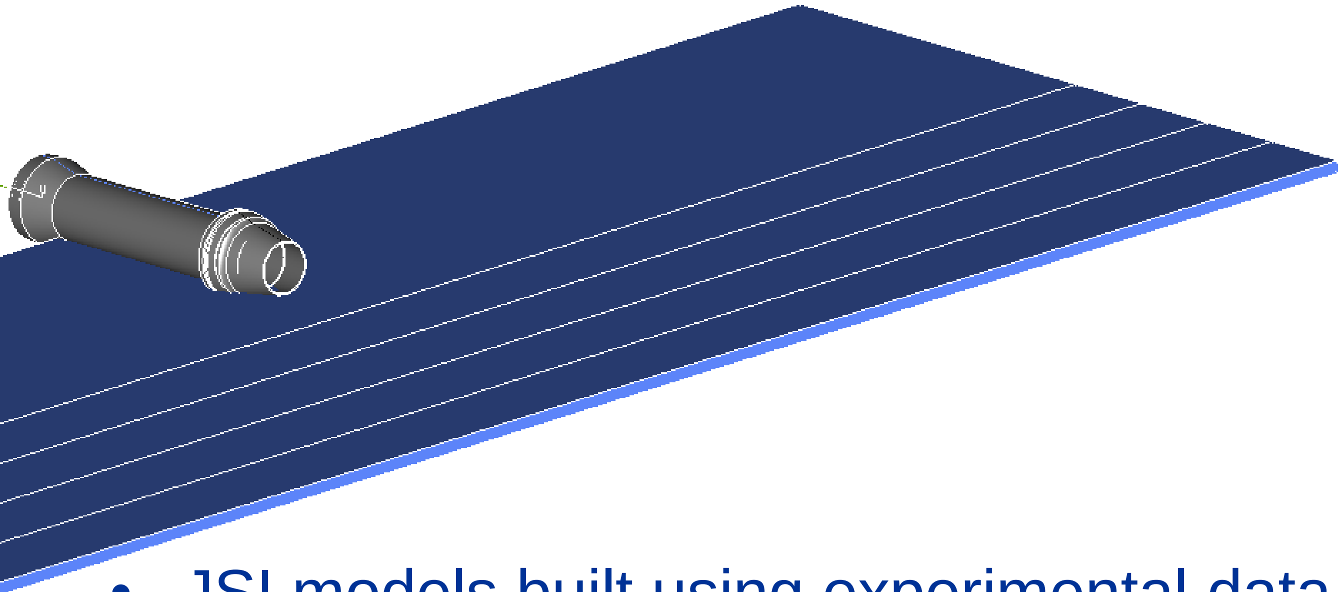
$$PSD = (P_M + G_{S/R}) \oplus P_d$$




- PSD computed from 2 sources
  - Jet-mixing noise ($P_M$)
  - JSI noise ($P_d$)
  - Add on POWER basis
- 1 effect
  - Shielding or Reflecting ($G_{S/R}$)
  - Add on a log (dB) basis
- Evaluate models for $P_d$ and $G_{S/R}$
  - Use experimental data for $P_M$



# Simple-Single-Stream (SSS) JSI Models



- JSI models built using experimental data where:
  - Single-stream subsonic jet (no plug) – no flight effects
  - Flat surface semi-infinite in 3 directions
  - Surface length and standoff distance vary
- JSI models assume*:
  1. Velocity and TKE axial profile collapses with jet potential core (Xc)
  2. Peak source distribution collapses with Xc

* Brown, AIAA 2015-0229, AIAA 2015-3128

# 3-Stream Multi-Planar JSI Geometry (JSI16)

- 3-stream nozzle system with plug
  - IV01 -> Internally Mixed
  - IV44 -> Inverted
  - IV19 -> Split
- Flight stream
- Dihedral center engine surface
  - Shielding (3 surface lengths)
  - Full-span
- Dihedral outboard engine surface
  - Reflection (1 surface length)
  - Partial-span
- Details in Bridges,AIAA 2018-0009


# Key Assumptions for JSI16 Predictions

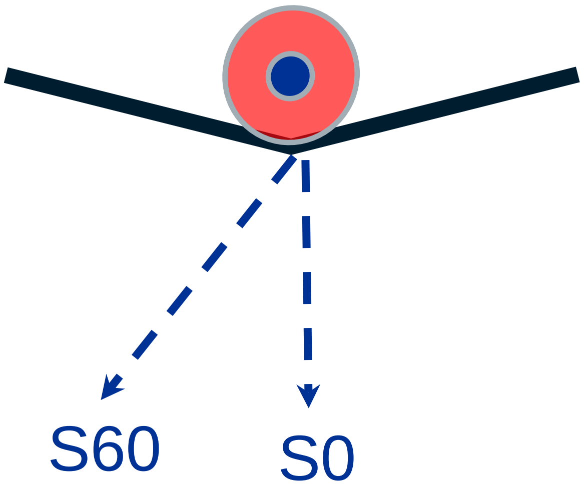
1. Multi-stream/IVP nozzles can be treated as single-stream using mass-weighted average temperature and velocity
   - JSI predictions use total temperature ratio and acoustic Mach number
   - JSI predictions rely on Xc -> use empirical multi-stream model*
2. Effect of partial-span surface vs full-span is small
   - Center engine is full-span w/shielding
   - Outboard engine is partial-span w/reflection
3. Effect of flight-stream is small
   - Mixing noise is most effected and shielding is a delta

* Bridges, AIAA 2016-2862

# EPNL Predictions

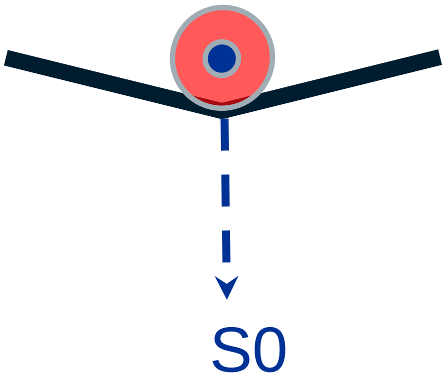
- JSI models are designed for system-level predictions where EPNL is key metric
- Linear Scale Factor (LSF) – model- to full-scale
  - IV01 -> 14 (Internally Mixed)
  - IV44 -> 14 (Inverted)
  - IV19 -> 11.8 (Split)
  - LSF is critical – scaling will weight shielding/reflection model frequencies in EPNL calculation
- Compute EPNL using:
  - Level flyover at 1000-foot altitude
  - Flight speed equal to free-jet velocity (static assumed Mach 0.3)

# EPNL – IV44 Nozzle – Center Engine

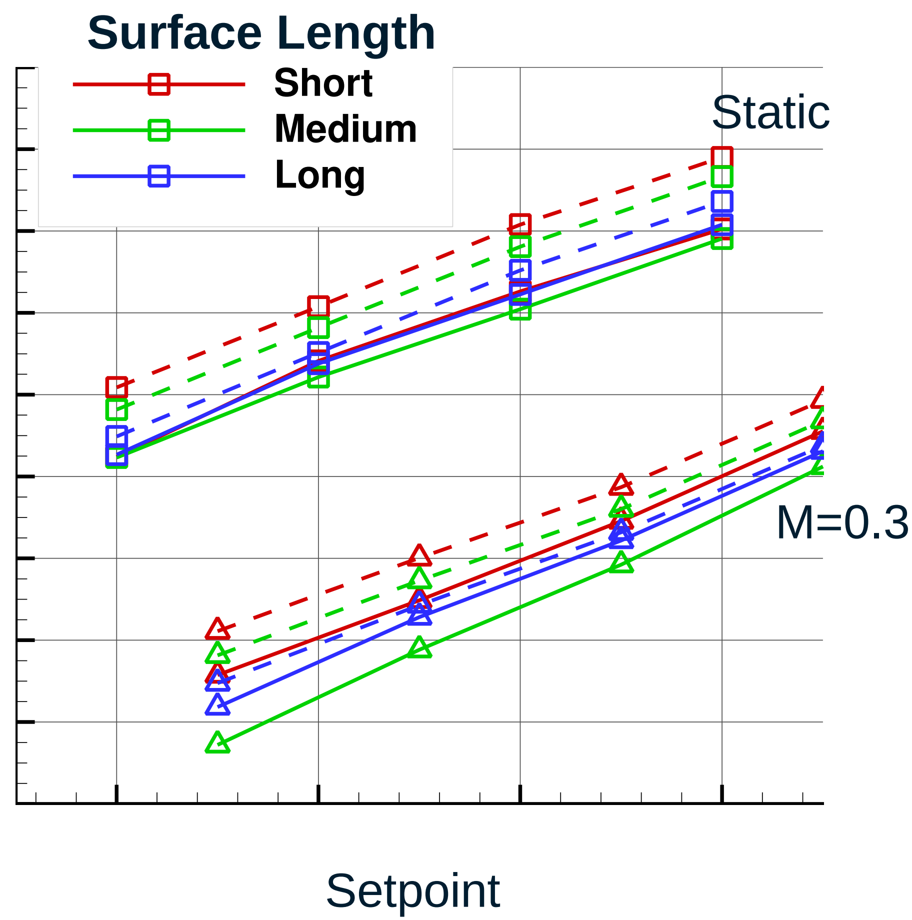



- Center engine geometry
  - Shielding
  - 3 surface length
  - Full-span

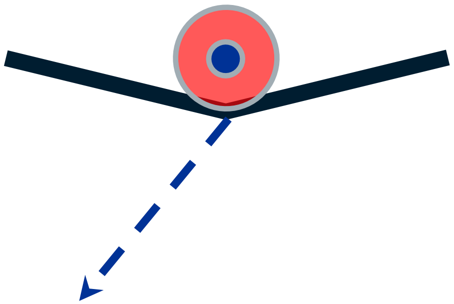
# EPNL – IV44 Nozzle – Center Engine



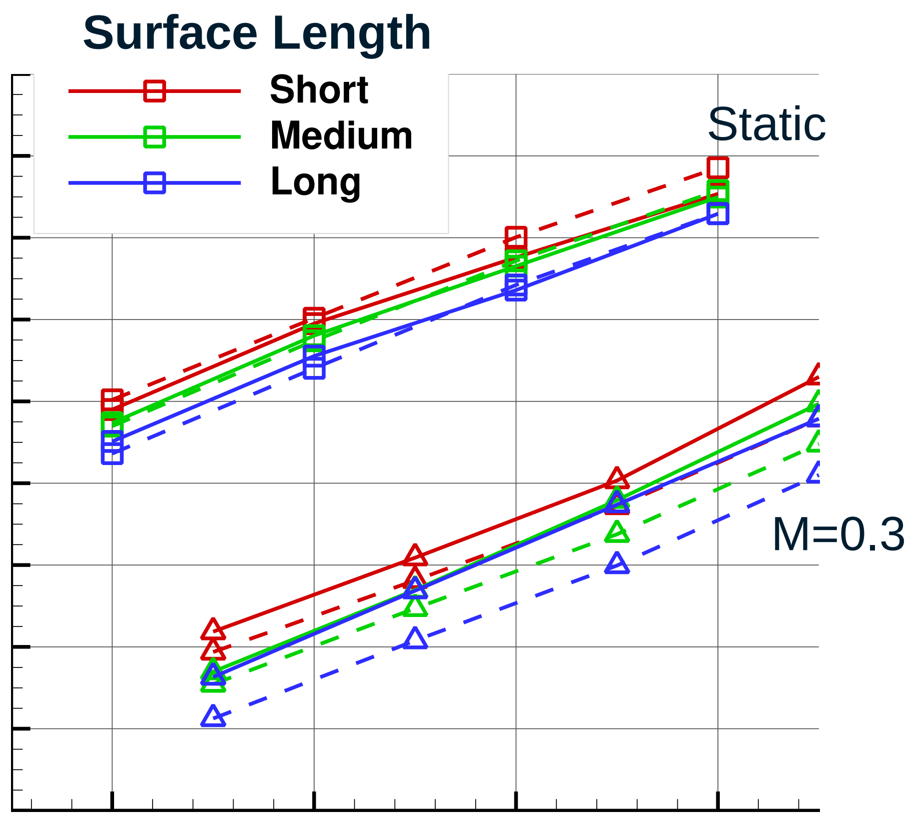

- Predictions more sensitive to surface length
- ±2 dB variation from data across cycle line



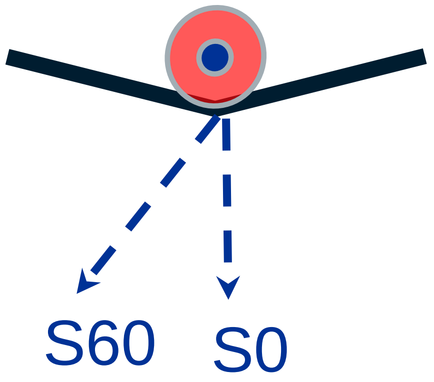
# EPNL – IV44 Nozzle – Center Engine

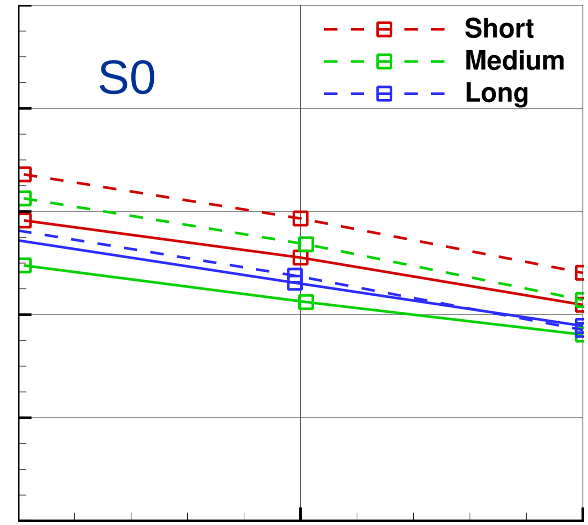


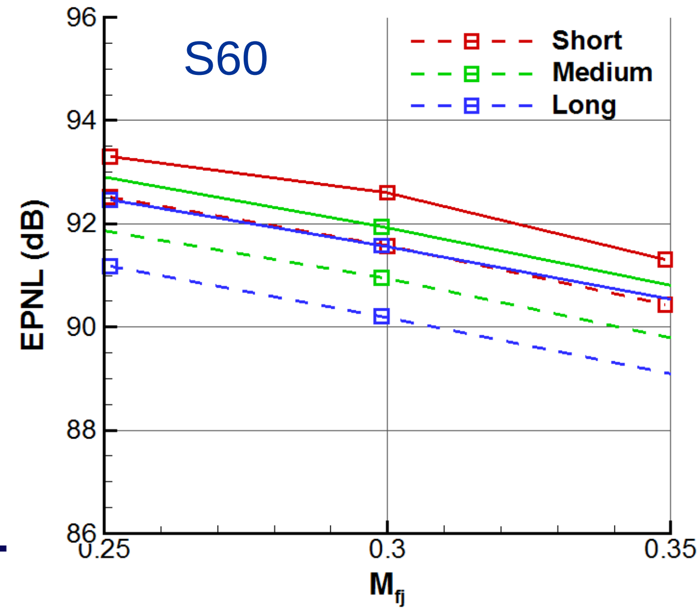

- ±2 dB variation from data across cycle line consistent with S0



# EPNL – IV44 Nozzle – Center Engine

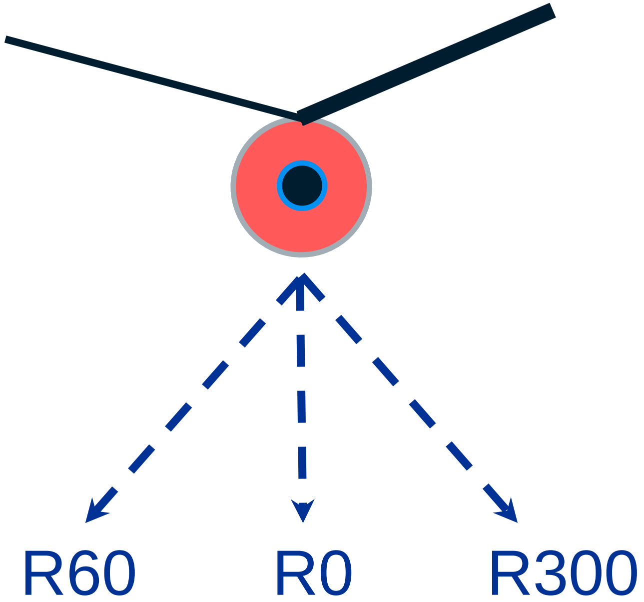


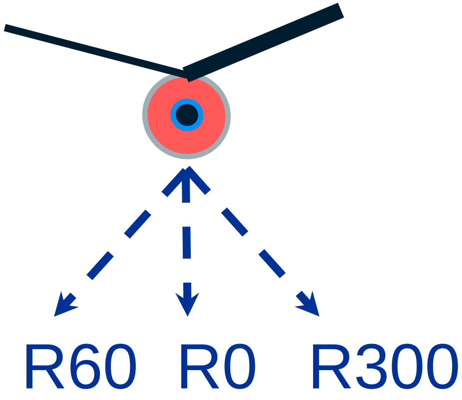

- Prediction is offset from data
- Slope matches as flight speed increases
- Flight primarily changes the jet-mixing noise
- Secondary role in JSI noise

# EPNL – IV44 Nozzle – Outboard Engine

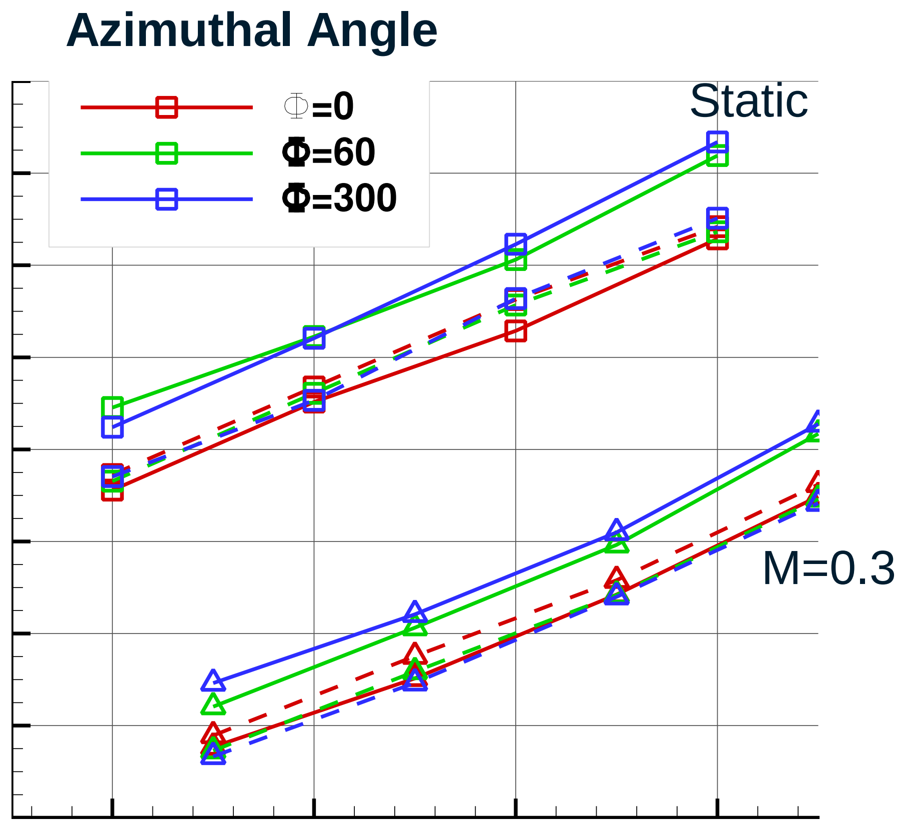



- Outboard engine geometry
  - Reflecting
  - 1 surface length
  - Partial span

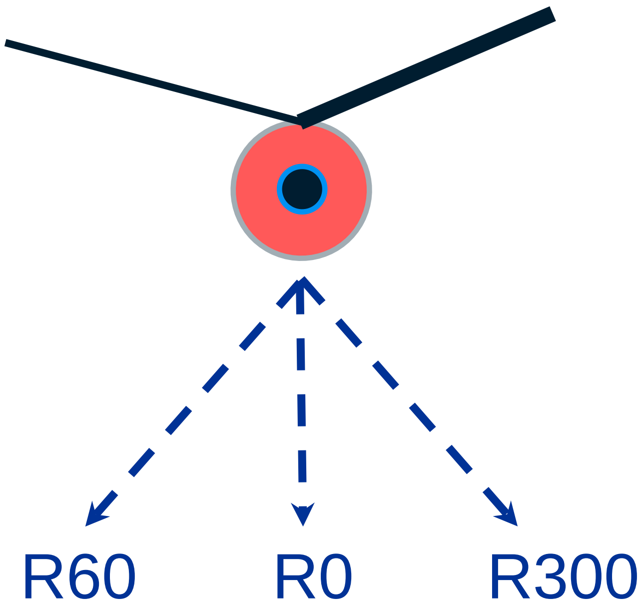
# EPNL – IV44 Nozzle – Outboard Engine

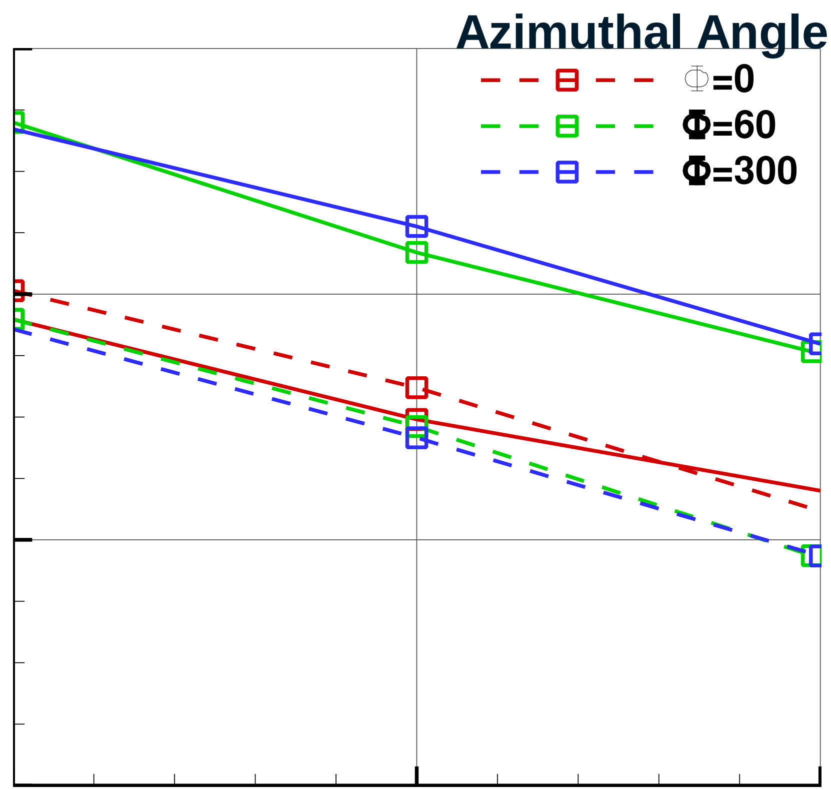



- ±2 dB variation from data across cycle line
- Consistent with S0/S60
  - Single-stream assumption is only constant in all cases



# EPNL – IV44 Nozzle – Outboard Engine

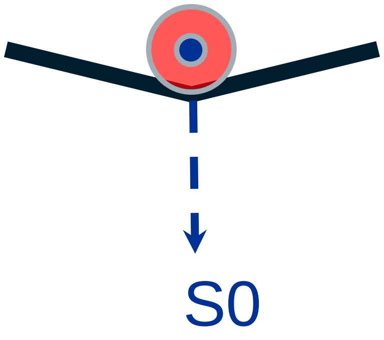


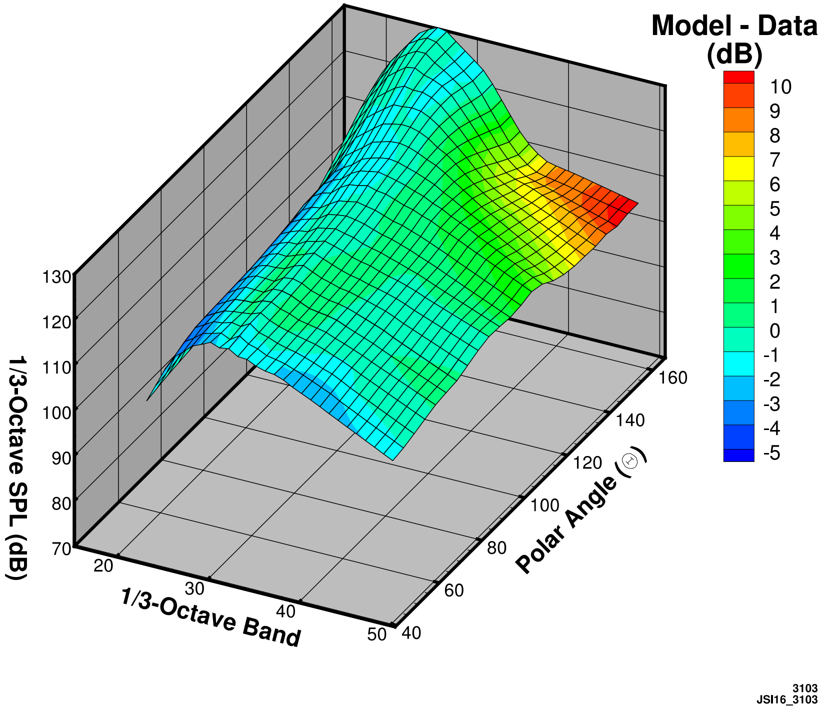

- Predictions are offset from data
- Slope matches as flight speed changes
- Flight effects have small part in JSI predictions

# Spectra – IV44 Nozzle – Center Engine

## Medium Surface - Takeoff (SP250)



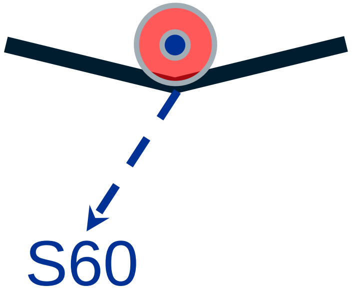

- Surface shape is predicted
- Color is (Model)-(Data)
- Largest discrepancy is downstream angles, high frequency
- Shielding model fails downstream
  - Source distribution relies on single-stream assumption*
- Surface may also change the jet mixing noise
  - PIV shows surface can change TKE



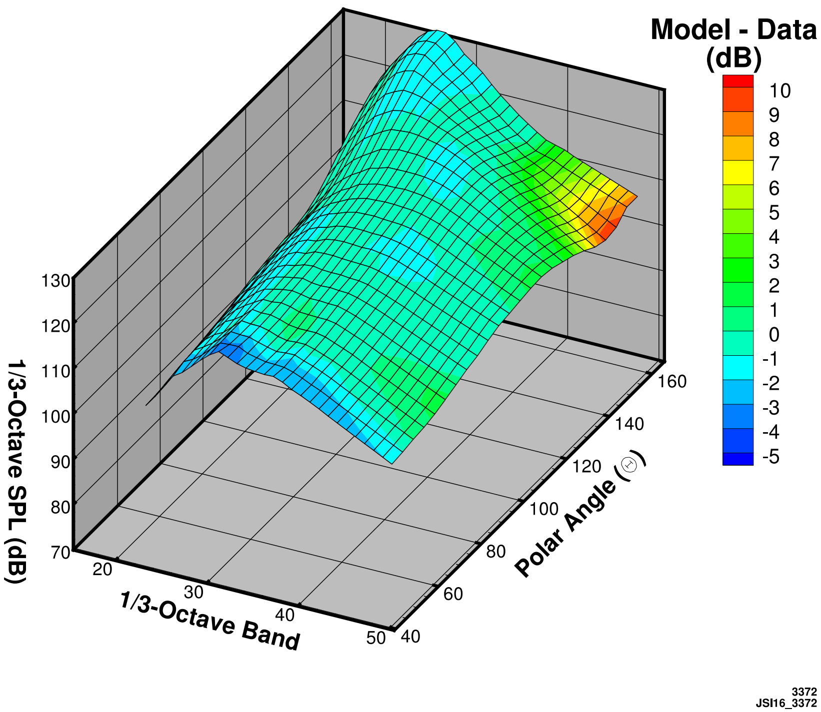

*AIAA 2016-2862

# Spectra – IV44 Nozzle – Center Engine

## Medium Surface - Takeoff (SP250)

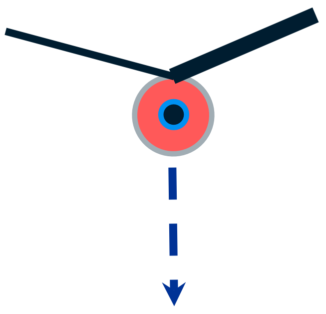



- Surface shape is predicted
- Color is (Model)-(Data)
- Largest discrepancy is downstream angles, high frequency
- Similar to S0
- Semi-infinite surface assumption is ok for center engine

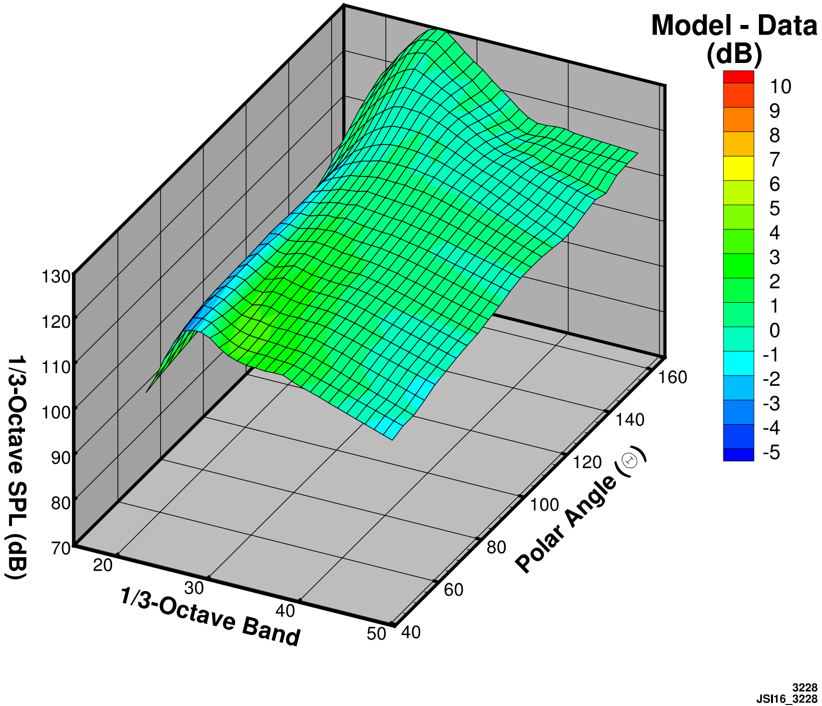


# Spectra – IV44 Nozzle – Outboard Engine

## Takeoff (SP250)

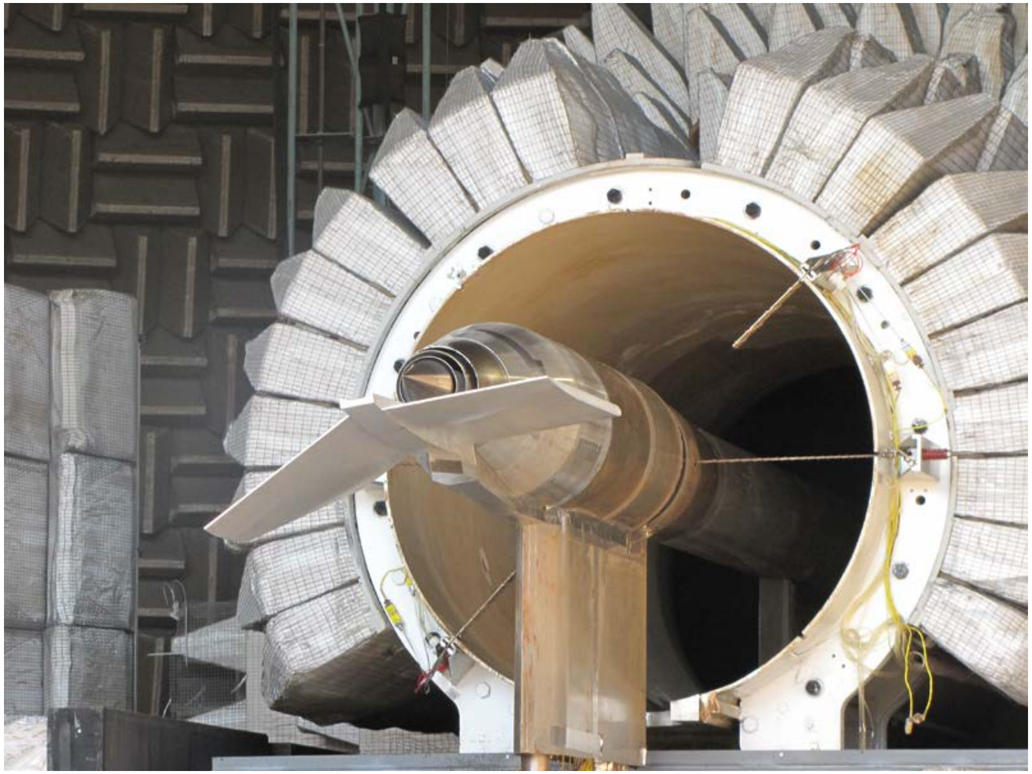


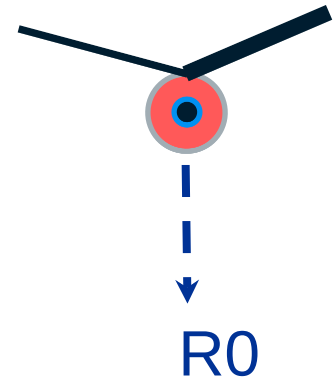

- Surface shape is predicted
- Color is (Model)-(Data)
- Largest discrepancy is downstream angles, high frequency
- +2 dB prediction across most frequencies/angles

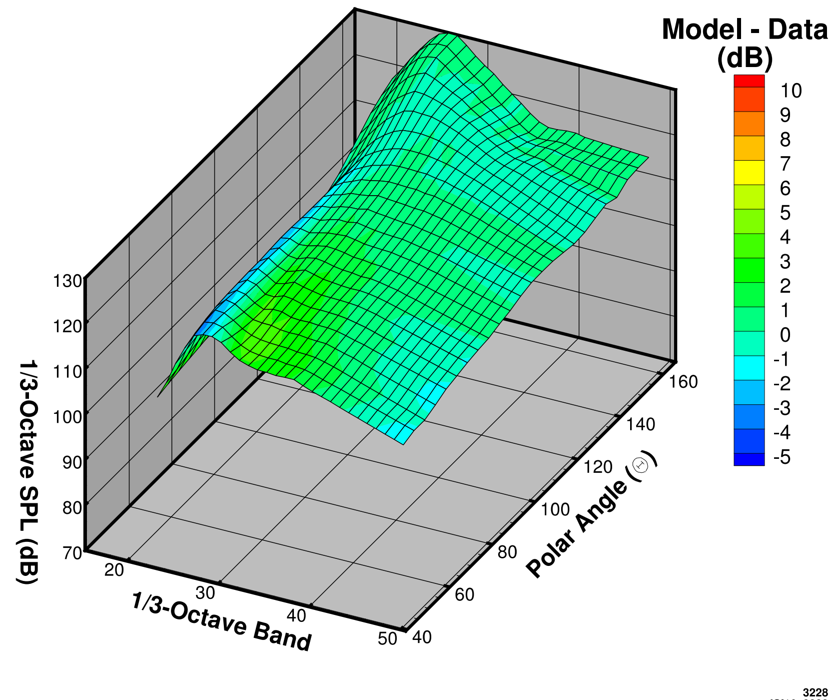


# Spectra – IV44 Nozzle – Outboard Engine

## Takeoff (SP250)



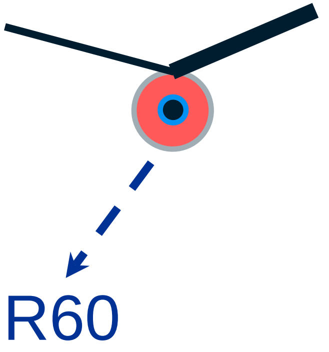


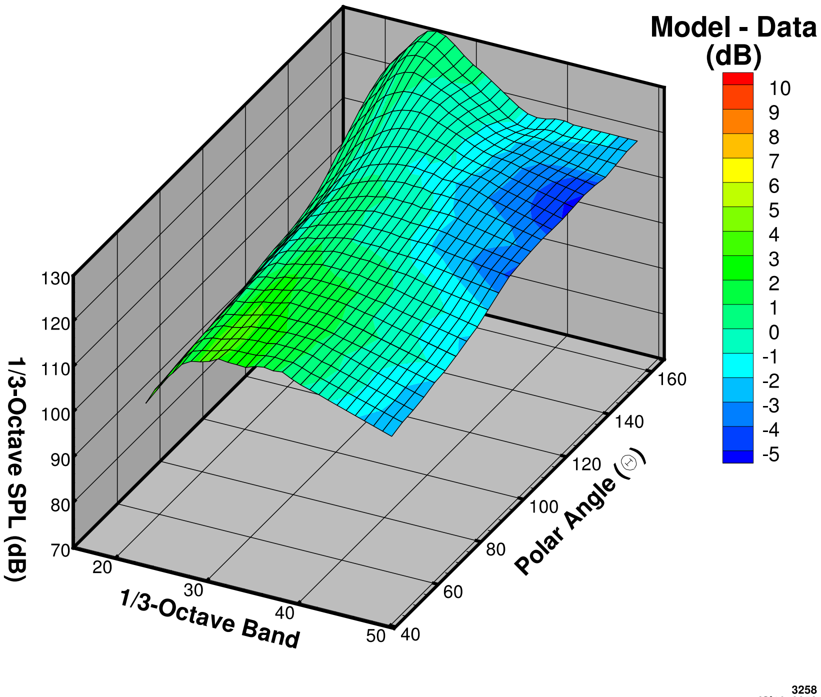



# Spectra – IV44 Nozzle – Outboard Engine

Takeoff (SP250)

- Surface shape is predicted
- Color is (Model)-(Data)
- Largest discrepancy is downstream angles, high frequency
- Reflection model underpredicts noise at broadside and downstream angles, high frequencies
- Semi-infinite flat surface span is poor assumption
- What else is happening here?



# Summary

- Simple-Single-Stream JSI models were applied to multi-stream nozzle with complex surfaces
- Assumed that multi-stream jets can be simplified to single-stream equivalents
  - Consistent offset between prediction and data for all setpoints/configurations shows this is a flawed assumption
- Assumed all surfaces can be treated as semi-infinite
  - Ok for center engine surface
  - Does not work for partial-span outboard surface
- Assume effect of flight is small
  - Flight mostly affects jet-mixing noise – lower priority assumption for the JSI models
- Overall: Models have an uncertainty around ±2 dB – on the order of the variation measured – which is unacceptably high

# Next Steps

- Need to improve the models
- Address multi-stream assumption
  - Systematic uncertainty
  - Shielding/Reflection models biggest impact on EPNL
  - Dependent on underlying noise source distribution models
  - Use CFD based source distribution or full CFD-based predictions?
- Address partial-span surfaces
  - Model exists for symmetric finite surfaces
  - Expand for partial surfaces?
- Payoff for flight effects model appears small -> low priority
- Installation can provide significant noise benefits